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SMITHSONIAN MISCELLANEOUS COLLECTIONS
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**Charles D. and Mary Vaux Walcott
Research Fund**

SEDIMENT TRANSPORT ON
SABLE ISLAND, NOVA SCOTIA

(WITH TWO PLATES)

By
NOEL P. JAMES
PAN AMERICAN PETROLEUM CORPORATION
CALGARY, ALBERTA, CANADA
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DIVISION OF SEDIMENTOLOGY
U. S. NATIONAL MUSEUM
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SEDIMENT TRANSPORT ON
SABLE ISLAND, NOVA SCOTIA

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(WITH TWO PLATES)

ABSTRACT

SABLE ISLAND, AN ARCUATE bar of unconsolidated sand about 24 miles long, is the only emergent point on the outer continental shelf off northeastern North America. A paleosol, probably as old as 6800 years B.P., covers aeolian sand deposited when most or all of Sable Island Bank was subaerially exposed during lower stands of sea level. These Pleistocene sands are orange to red as a result of coatings of ochreous hematite on quartz grains.

Abrasion and selective transportation during the Holocene have removed the iron-stain coating and altered the mineralogical composition of the sands above the paleosol. Lateral distribution of these sands suggest that (1) the north and south sides of the island are subject to different physical conditions and that (2) the net sediment movement is toward the northeast.

Beach and dune sands can be differentiated only on the basis of texture. A mean grain size versus sorting plot is useful when large-scale movement of sediment with little selective sorting takes place, but when sediment has been subjected to prolonged selective sorting a skewness versus kurtosis plot is more useful.

The backbone of the island, two parallel east-west trending dune chains, occupies the median position between strong winter winds from the northwest and gentle summer winds from the southwest. The

interaction between wind and waves, both seasonal in character, causes cyclical movement of sediment from the island to the sea and back again. Although Sable Island is being slowly displaced toward the east, it is not being destroyed as predicted in previous studies.

ACKNOWLEDGMENTS

We are indebted to the Department of Transport of Canada for enabling us to carry out a research program on Sable Island in May 1965. Personnel of the Meteorological Branch stationed on the island were not only extremely helpful, but also made our stay a particularly enjoyable one. Dr. F. Medioli of the Department of Geology, Dalhousie University, was a member of the expedition and participated in the collection of samples and in mapping. Carbon-14 dates of the paleosol were obtained from Dr. K. Kigoshi, Gakushuin University, Tokyo, Japan, and the Geological Survey of Canada, Ottawa, Canada. The Institute of Oceanography, Dalhousie University, and the National Research Council of Canada provided funds and facilities necessary to conduct this study.

INTRODUCTION

PURPOSE OF STUDY

Sable Island, lying atop the broad, shallow, sediment-covered Sable Island Bank (roughly 120 miles southeast of Cape Canso, Nova Scotia), is a geomorphic oddity. This island, the only emergent point on the outer continental shelf off eastern North America (fig. 1), is composed entirely of unconsolidated sediment and lies in the open ocean far from the coast. It has few counterparts in today's oceans.

The purpose of this study is to determine the sediment distribution and dominant paths of sediment transport on Sable Island, and to interpret the physical parameters and processes causing this movement. As Sable Island offers an opportunity to conduct a controlled study of the interaction of wind and water on an isolated sand body, criteria valuable in distinguishing adjacent depositional environments, particularly beaches and dunes, are investigated. This study was initiated as part of a more extensive investigation of the sediment dispersal patterns on Sable Island Bank and adjacent areas, the results of which are presented elsewhere (Stanley *et al.*, 1967; James and Stanley, in press).

DESCRIPTION OF SABLE ISLAND

Sable Island is an arcuate bar of sand approximately 24 miles long, $\frac{7}{8}$ mile wide at its widest point, and only a few hundred yards wide at its terminal extensions (fig. 2). It lies at about 60° West Longitude and 44° North Latitude. The central 'core' of the island is composed of sand dunes stretching discontinuously $17\frac{1}{2}$ miles from east to west.

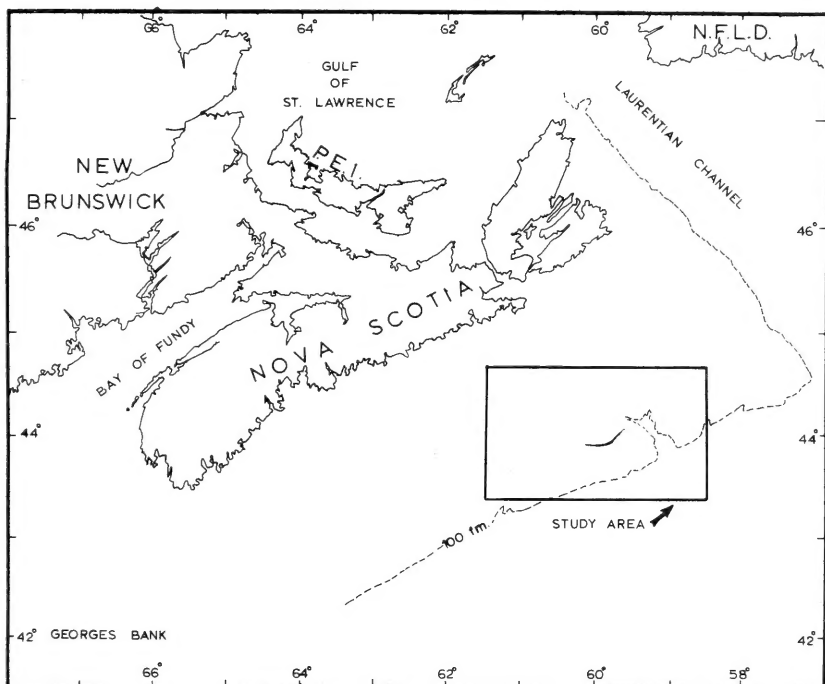


FIG. 1.—Nova Scotia and the surrounding continental shelf. The framed area denotes the region encompassed by this study.

Narrow, subaerially exposed bars extend beyond these dunes for several miles.

A series of large parallel dune ridges, oriented east to west, form the backbone of the island. Dunes average 20 to 50 feet in height, with steep dune scarps, free of vegetation, facing the sea on both sides of the island. Dune slopes, covered with sparse vegetation, slope gently toward the center of the island forming a sheltered hollow. The dunes are breached by several large blowouts oriented northwest to southeast (figs. 2 and 16).

The south-central portion of the island is occupied by Lake Wallace,

a shallow brackish lake (fig. 2). The dune ridge south of the lake has almost been destroyed, resulting in a large beach flat. Areal extent of the lake depends upon precipitation and wind; the latter has a tendency to drive lake water onto the sand flats.

A lens or wedge of fresh to brackish water rests on salt water beneath much of the island. This wedge is the result of rainfall and snow-melt accumulating above the salt water. Numerous fresh water ponds occur in the central portion of the island where the water table lies close to the surface. Vegetation is most prolific around these small ponds, and boglike patches with abundant cranberry growth are common in low areas.

PROCEDURE

FIELD WORK

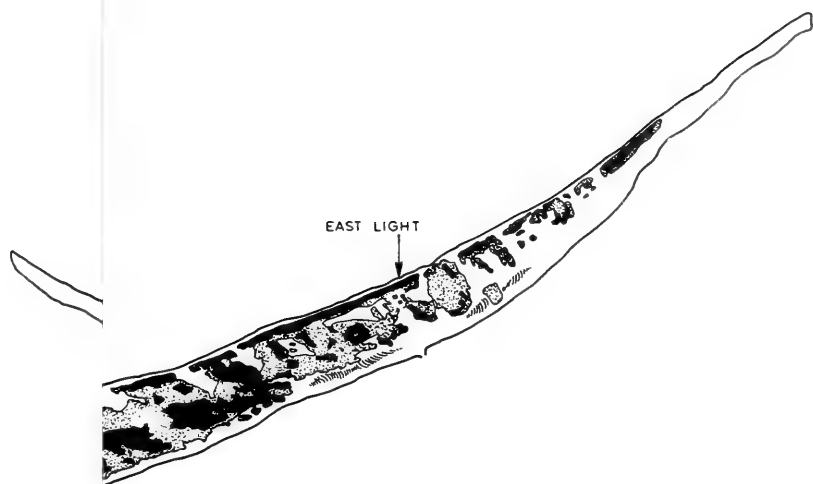
Field work was divided into three phases. First, a map outlining the distribution of different surface sediment types was prepared (fig. 8) and an ancient soil horizon (a paleosol) mapped. Secondly, dominant environments were sampled on a grid system. Cameron's (1952) detailed base map of the island was used to locate sample stations. The top 6 cms. of sediment were sampled along 22 lines running north-south across the island (fig. 3). Thirdly, samples were taken at localities where the paleosol crops out (fig. 4). At each paleosol outcrop three samples were collected: one of sand 5 to 10 feet below the paleosol (paleosand), one of the paleosol horizon proper, and one of sand 5 to 10 feet above the paleosol (neosand).

LABORATORY ANALYSIS

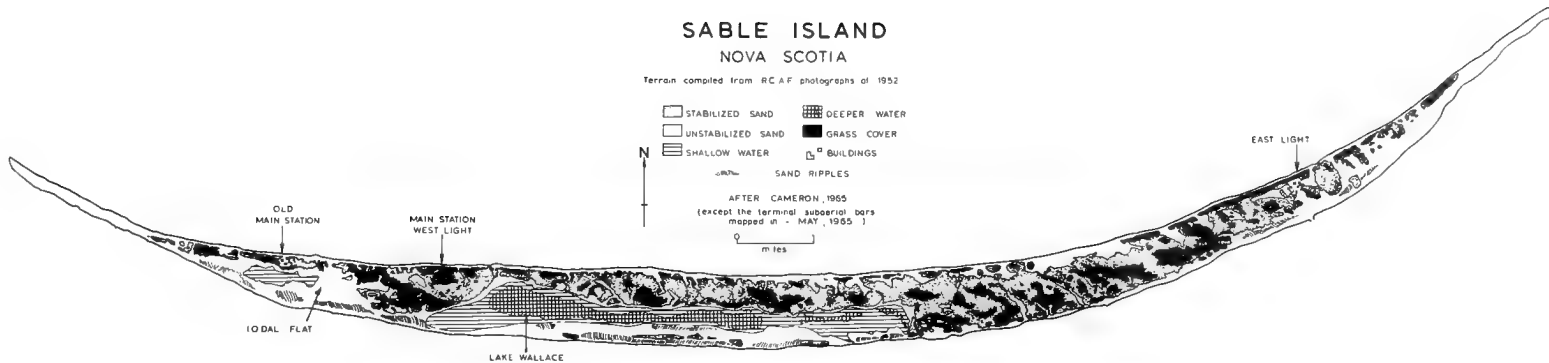
Mineralogy.—The 47 samples examined consist of sand size material. Each sample was split into five Wentworth size fractions and each fraction examined using a modification of Shepard's (1954) technique. A total of 300 grains from each fraction were counted and identified.

The 125 to 250 micron size fraction, consistently rich in heavy minerals, was selected for heavy mineral study. In each sample, an opaque-nonopaque ratio was first established by counting 200 grains. Specific transparent heavies were then identified in a separate count of 100 nonopaque heavy minerals.

Texture.—Size analysis of 138 samples was made with a slightly modified version of the Woods Hole Rapid Sediment Analyser (Schlee, 1966). This analyser measures changes induced in the water







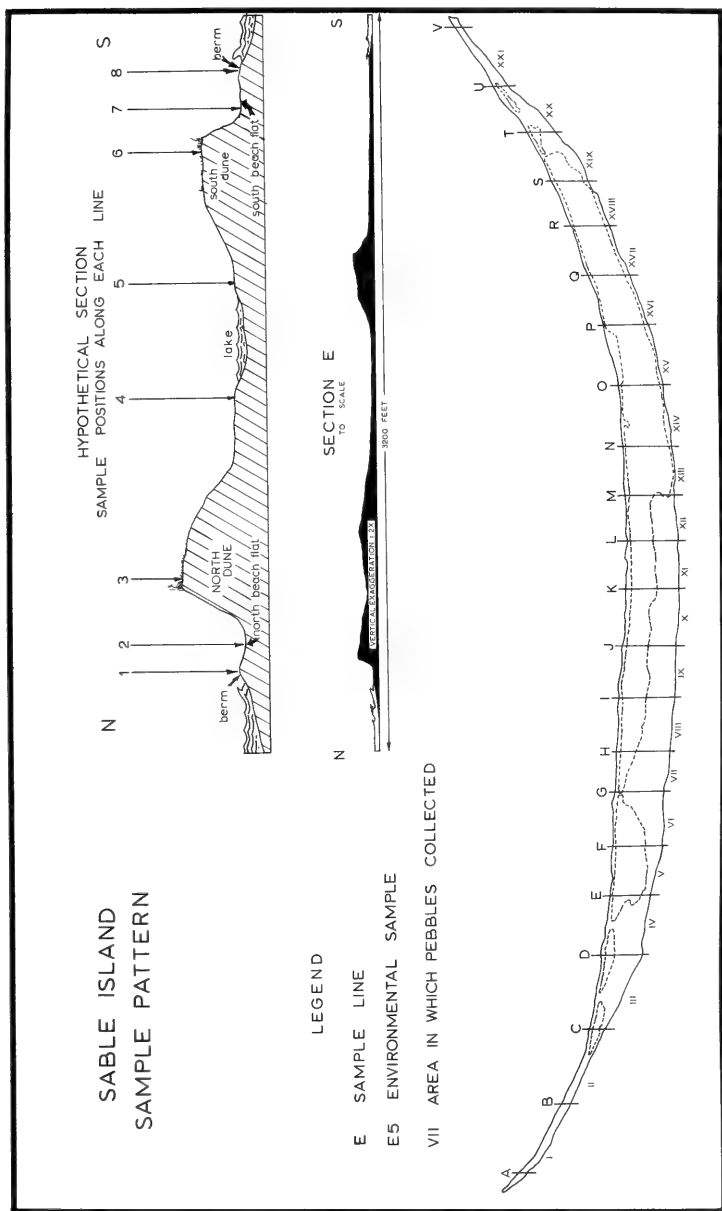


FIG. 3.—Sample pattern followed on Sable Island. Samples were collected along each sample line in different environments. Note the high dunes on either side of the island.

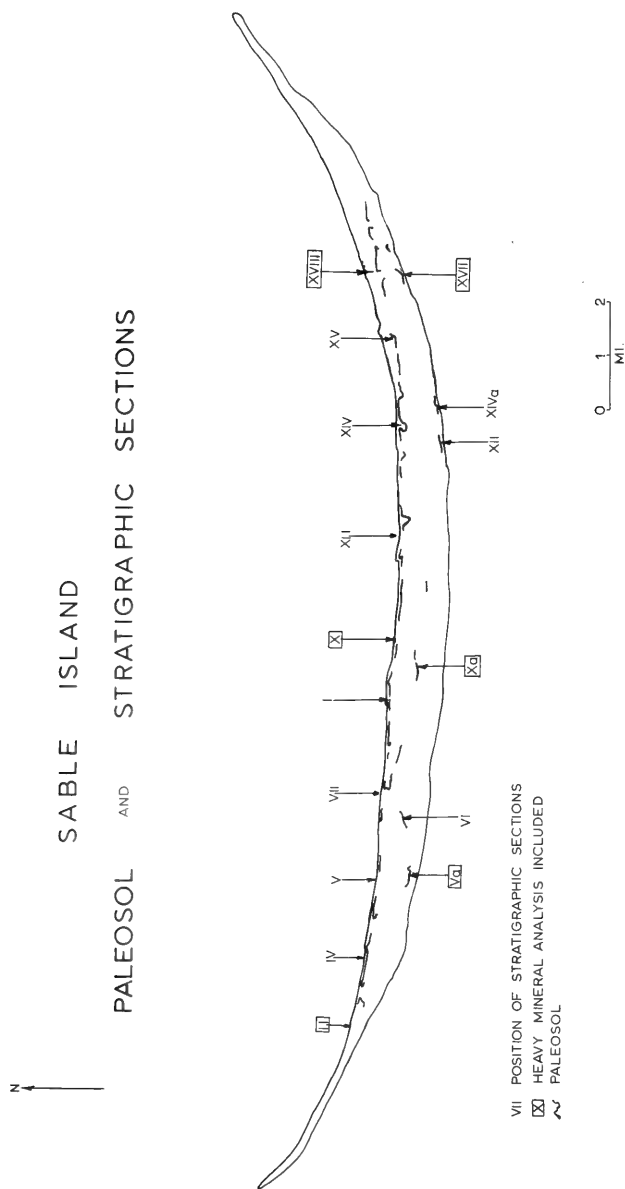


FIG. 4.—Exposures of the paleosol on Sable Island, indicating positions of the stratigraphic sections (modified after Medioli *et al.*, 1967). Sample numbers enclosed in a box indicate heavy mineral analysis as well as binocular coarse fraction study.

column by sediment settling through a measured distance. Samples weighing between 5 and 10 grams were used and the settling time converted to equivalent Φ size. A size interval of $\frac{1}{4}\Phi$ was used. The basic difference between this method and sieve analysis is that the former is measuring the frequency of a specific size range, not by weight, but by fall velocity.

The following formulae, after Folk and Ward (1957), were used to summarize the size distribution :

Central Tendency (Mean size)	$M_z = \frac{\Phi_{16} + \Phi_{50} + \Phi_{84}}{3}$
Sorting (Standard deviation)	$\sigma_1 = \frac{\Phi_{84} - \Phi_{16}}{4} + \frac{\Phi_{95} - \Phi_5}{6.6}$
Asymmetry (Skewness)	$Sk_1 = \frac{\Phi_{16} + \Phi_{84} - (2)\Phi_{50}}{2(\Phi_{84} - \Phi_{16})} + \frac{\Phi_5 + \Phi_{95} - (2)\Phi_{50}}{2(\Phi_{95} - \Phi_5)}$
Peakedness (Kurtosis)	$Kg = \frac{\Phi_{95} - \Phi_5}{2.44(\Phi_{75} - \Phi_{25})}$

Textural parameters were calculated with an electronic computer using a modified IBM Fortran IV program introduced by Kane and Hubert (1963). Complete tabulated sample data is given in James (1966) and is also available from the National Oceanographic Data Center in Washington, D.C.

RELICT SANDS ON SABLE ISLAND

PALEOSOL

A humus horizon, recognized as a fossil soil or paleosol, ranges from 3 to 30 cms. in thickness and crops out along many of the steeply dipping dune faces (fig. 4 and plate 1, fig. 1). This organic layer protects the sands below it and, in effect, controls the physiography of the island (Medioli, Stanley, and James, 1967).

Radiocarbon analyses of the paleosol provided dates averaging from 200 to 240 years B.P. (fig. 5). We feel that these dates are questionable because of the contamination of old plant material with recent plant debris. When the paleosol lies adjacent to the water table, it always acts as an organic base for the growth of modern vegetation.

Other lines of evidence also suggest that the paleosol is much older :

(a) The present soil-cover on most of the island is almost negligible. Historical records show that 200–300 years ago vegetation on the island was similar to that of today.

(b) Large-scale cross stratification in the lower sand (plate 1,

fig. 2), in contrast to the small-scale structures in the upper sand, suggests that the lower sand was deposited on a much larger exposed area, subject to more active aeolian processes than are present today (possibly windblown periglacial flats prior to and during the early Holocene transgression).

(c) Ellipsoid-shaped balls of peat, similar to the paleosol, are found on beaches. These peat balls have been eroded from the paleosol, or probable extensions of it that presently crop out below sea level. A peat ball of this type yielding an age date of 6800 ± 150 B.P. was collected in 30 feet of water offshore (fig. 5). This

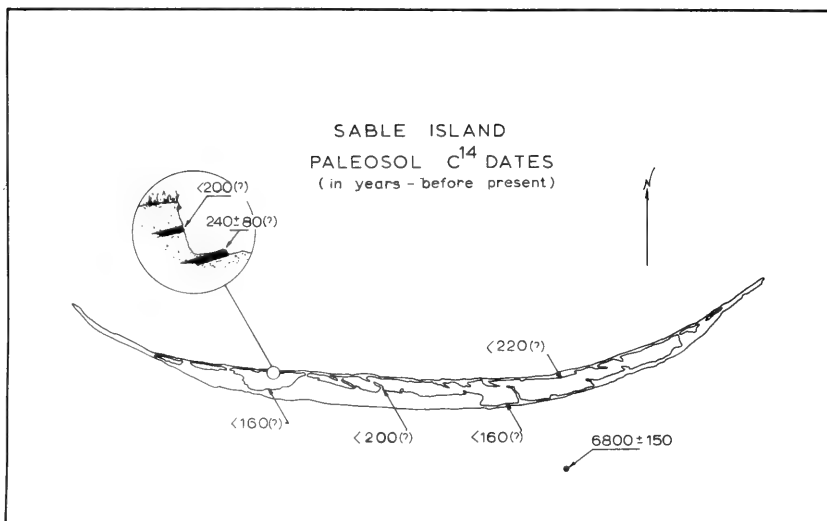


FIG. 5.—Carbon-14 age determinations of the paleosol on Sable Island and of a peat ball dredged up in 30 feet of water offshore. Ages of the paleosol are in doubt because of contamination by recent vegetation. The paleosol may be as old as the peat material collected offshore.

may represent an uncontaminated portion of the paleosol, suggesting that the paleosol is actually much older than 300 years B.P.

(d) Shell material collected on Sable Island indicates that a period of milder climatic conditions occurred in this region about 6000 years B.P. (Clarke *et al.*). This period of warming corresponds closely with the age of the peat ball described in (c) and can be related to the post-glacial thermal maximum, or *hypsiothermal*. It is probable that the development of vegetation and of a humus-peaty surface horizon (preserved as the paleosol) were favored during this temporarily warmer climate.

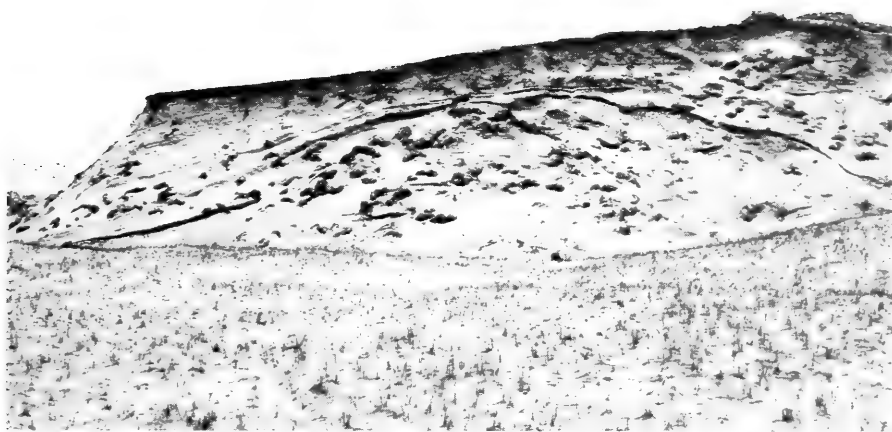


FIG. 1.—Paleosol (section Xa, fig. 4) illustrating its control of the dune morphology. It arches up in anticlinal fashion under the dune crest and drops below the adjacent blowout areas.

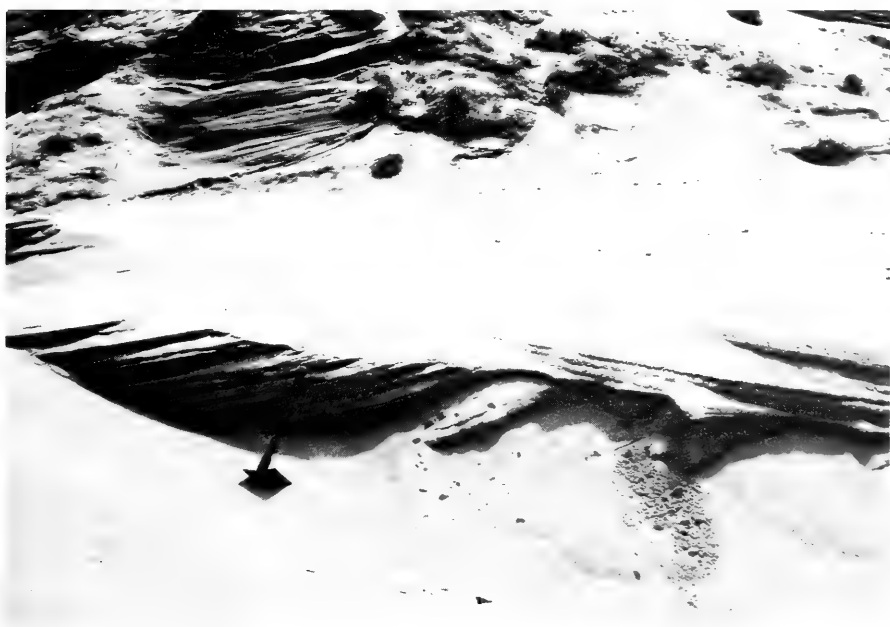


FIG. 2.—Large-scale trough cross-stratification in the sand below the paleosol (section XVIII, fig. 4). Spade gives scale.



FIG. 1.—Blowout breaching the dune chain on the northern side of Sable Island. Photo oriented toward west, on sample line i (see fig. 3). Note Sable Island ponies on distant dune and Lake Wallace on left of photo.



FIG. 2.—Shell and pebble facies on south beach. Note the dark linear patches of heavy mineral concentrations, aligned subparallel to the dune and beach, which result from winds blowing toward the northeast. This trend is indicated also by scour marks around pebbles.

SANDS ABOVE AND BELOW THE PALEOSOL

The major difference between sands lying above and below the paleosol is color; the upper neosand is buff-grey (2.5Y 7/4) and the lower paleosand red to orange (10YR 6/6). The paleosand also possesses large festoon or cross-stratification structures which are not as well developed in the upper sand.

The mean grain size of the neosand is 1.4Φ (0.49 mm.), slightly coarser than the 1.5Φ (0.35 mm.) mean size of the paleosand. When the entire distribution curve is plotted, no apparent difference is noted between the sands, suggesting that processes controlling texture have been relatively constant since deposition of the paleosol.

When quartz types are plotted on a triangular diagram, with clear quartz, milky quartz, and iron-stained quartz as end members, the two sands occupy different fields (fig. 6). Reddish iron-stained quartz is more abundant in the paleosand. This separation is apparent whenever stained quartz is used as an end member, suggesting that iron-stained quartz is imparting the reddish color to the lower paleosand.

Heavy mineral analyses made on 6 of the 16 paleosol sections indicate that the neosand contains more heavies than the older sand lying below it (fig. 7). The neosand is also richer in opaque heavies (magnetite and ilmenite) and garnet. The paleosol correspondingly contains relatively greater percentages of the minor heavies (brookite, kyanite, andalusite, epidote, and augite). A χ^2 test applied to the heavy mineral results indicates that the mineralogical composition of the two sands is significantly different (James, 1966).

INTERPRETATION

Textural data indicates that processes responsible for the movement of sands on Sable Island have been consistent since deposition of the sands lying below the paleosol. The significant difference between the old and the younger sands is mineralogical. The reason for the greater amount of iron-stained quartz in the paleosand is puzzling until considered in the light of heavy mineral data.

The paleosand contains a smaller percentage of opaque minerals, for the most part magnetite, than does the neosand. Norris (1965) indicates that windblown sands show a consistent color change through time from white or grey to deep red. This color change is attributed to the gradual transformation of magnetite to coatings of ochreous hematite on quartz and feldspar grains. These coatings thicken and affect larger numbers of grains with the passage of time while the

percent of magnetite grains is correspondingly reduced. Grains in the paleosand are generally well coated suggesting that the paleosand may be considerably older than the neosand.

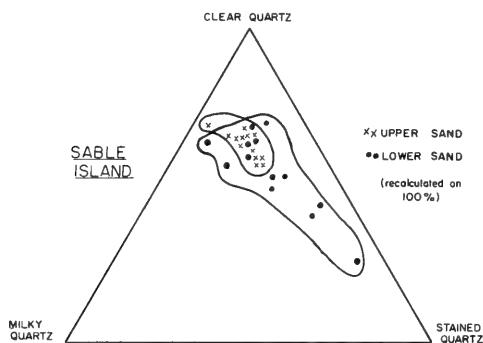


FIG. 6.—Three types of quartz found in the two sands plotted as end members of a triangular diagram. Note that iron-stained quartz tends to be more abundant in the lower sand (paleosand).

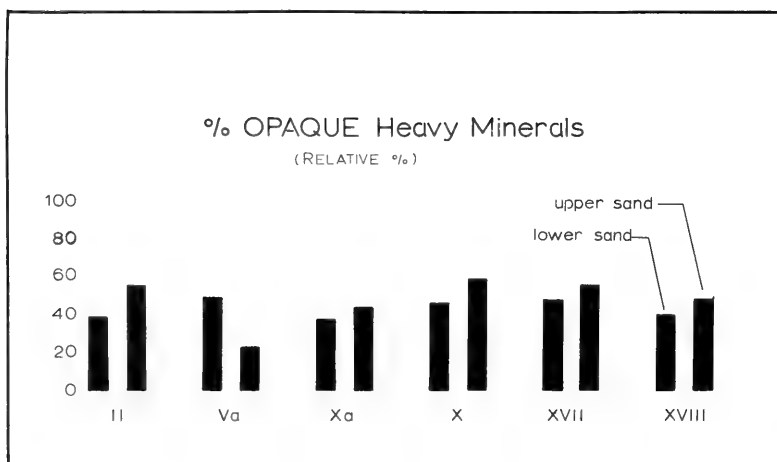


FIG. 7.—Relative percent of opaque heavy minerals in the heavy mineral portion of the 125 to 250 micron size fraction of neosands and paleosands. Note that the neosand contains a relatively greater percentage of opaques.

Intrastratal solution does not seem to have affected the heavy minerals, as indicated by the absence of etched surfaces and hacksaw terminations on the less stable grains (Neiheisel, 1962) in the paleosol. Reduction in the number of these less stable grains in the neosand and relative increase in the stable mineral garnet (Pettijohn, 1957; Dryden

and Dryden, 1946) indicate that reworking of the paleosand has destroyed or removed the unstable species and in the process made the neosand mineralogically more "mature." Abrasion may also have removed the hematite coatings from the quartz grains in the neosand.

In conclusion, the neosand is mineralogically more mature than the paleosand. Older sands, deposited when the bank was subaerially exposed, have served as the source for the neosand. Iron-stained grains of the paleosand can be used as one of the mineralogical tracers to indicate dominant directions of sediment transport. These petrographic differences also support the conclusion that the paleosol horizon is at least of Holocene age.

SEDIMENT DISTRIBUTION ON SABLE ISLAND

GENERAL

Areas rich in heavy minerals, pebbles, shells, and peat balls are shown on the sediment facies map (fig. 8). Bars at either end of the island and segments of the south beach contain particularly high concentrations of pebbles and shells suggesting frequent incursions of the sea. Egg cases of skate, common on the wide south beach flats, also indicate that the sea periodically transgresses inland as far as the base of dunes, especially during storms. The south beach contains somewhat larger amounts of heavy minerals, shells, peat balls, and pebbles than does the north beach.

LATERAL TEXTURAL DISTRIBUTION

Mean grain size (fig. 9A).—Mean size, a measure of the central tendency of the size distribution, can be used to represent the "average" grain size. Mean grain size values of sands on Sable Island range from $+2.44\Phi$ (0.184 mm., fine sand) to $+0.75\Phi$ (0.595 mm., coarse sand), but most have a mean size ranging from $+1.75\Phi$ (0.297 mm.) to $+1.50\Phi$ (0.354 mm.), medium sand. Coarsest sand ($<1.5\Phi$) is found along the northern side of the island, and on the south beach, south of Lake Wallace. Finest sand ($+1.75\Phi$) occurs on the south of the island between the eastern end of Lake Wallace and the East Light.

Sorting (fig. 9B).—The measure of "spread" of the distribution curve can be summarized by calculating standard deviation. This parameter is also a measure of the degree of sorting (the lower the standard deviation value, the better sorted the sample). Folk and Ward (1957) indicate that a sample with a sorting value of 0.35Φ

or less is very well sorted, between 0.35Φ and 0.50Φ well sorted, and between 0.50Φ and 0.71Φ only moderately well sorted.

Very well sorted sand is found along the southeastern margin and western side of the island. The most poorly sorted sand is found on the northeastern side of the island.

Skewness (fig. 9C).—Skewness is a measure of the asymmetry of the distribution curve (a normal or symmetrical curve has a skewness of 0.00; positive values indicate an excess of fines; negative values

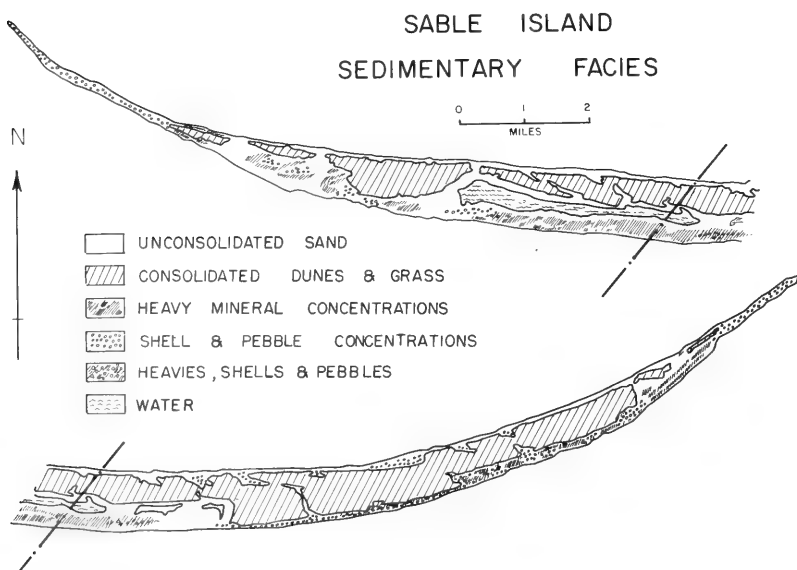


FIG. 8.—Map of the various sedimentary facies present on Sable Island.

indicate an excess of coarse material). The greater the skewness the greater the asymmetry of the distribution curve.

From the east end of Lake Wallace, south of the northern dunes, to the west end of the island the sand is fine skewed. Most sand on the northeastern margin of the island is coarse skewed.

Kurtosis (fig. 9D).—Kurtosis is an expression of the peakedness of the size distribution curve and indicates that portion of the distribution curve which is better sorted, i.e., the “tails” or the central region. All samples on Sable Island are “platykurtic” (Folk and Ward, 1957) indicating that the “tails” on the size curve are better sorted.

INTERPRETATION OF TEXTURAL DISTRIBUTION

The entire northern portion of the island contains relatively coarse sand; it is better sorted in the northwest sector. On the northeastern sector, sand is coarse skewed, due perhaps to effects of relatively stronger wind and wave attack in that sector.

Texture of the sand on the southern portion of the island is more varied. South of Lake Wallace sand is coarse, of average sorting, and fine skewed. East of the lake sands become finer, very well sorted, and nearly symmetrically skewed. The brunt of wave attack on the south side tends to concentrate coarse sediment south of Lake

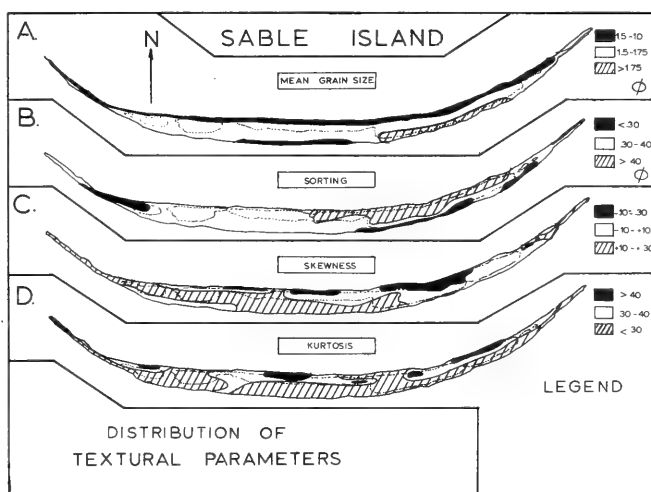


FIG. 9.—Textural variation of sediment on Sable Island (parameters calculated after Folk and Ward, 1957).

Wallace. A decrease in mean grain size and increase in sorting eastward suggests an eastward transport of sediment by beach drift. The fine skewness of the coarser sand south of Lake Wallace results from fine material being added to the coarse lag deposits by longshore drift from the west.

LATERAL MINERALOGICAL DISTRIBUTION

Quartz (fig. 10).—The relative percentage of iron-stained quartz is greatest along the northern and eastern portions of the island. This may be the result of: (1) removal of the coating by abrasion on the south and (2) progressively greater addition of iron-stained grains from the paleosand in the direction of sediment movement.

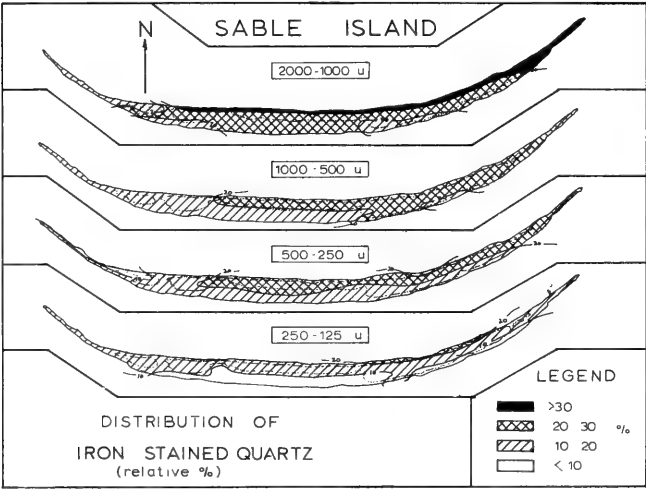


FIG. 10.—Relative percent of iron-stained quartz in the various size fractions (calculated from the total quartz content only) in Sable Island sediment.

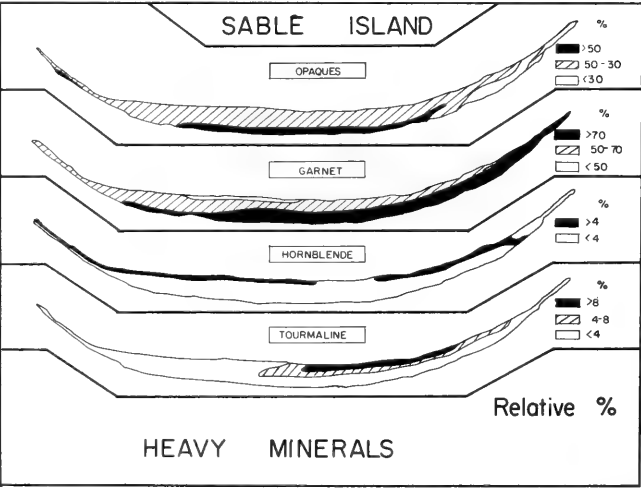


FIG. 11.—Relative percent of various heavy minerals in the 125 to 250 micron size fraction including opaque heavies (percent of the total heavy mineral fraction), garnet, hornblende, and tourmaline (percent of the transparent portion only).

Rock fragments.—Lithic fragments are concentrated in areas that are rich in pebbles and shell fragments, suggesting that lithic grains are derived, in part, by the abrasion of pebbles.

Heavy minerals (Fig. 11).—The specific gravity of the heavies range from 3.1 (tourmaline) to 5.2 (magnetite). Greatest concentrations of heavies occur at the base of dunes along the beaches, particularly on the southern margin of the island, east of the meteorological station. This is not in every case a true reflection of the total heavy mineral assemblage, but rather of garnet and magnetite which make up about 70 percent of most heavy mineral fractions.

Garnet, the most prolific of the heavies, comprises from 48 percent to 75 percent of the nonopaque fraction. This relatively resistant, dense, and large mineral species (sp. gr. 4.0) probably accumulates as a lag on the southern and eastern margins of the island in regions where there is continual movement of the coarser, well-sorted sediment.

The distribution of magnetite and zircon, both dense, resistant minerals, follows that of garnet, suggesting that they also accumulate as a lag in the same areas.

Zircon, tourmaline, and rutile represent an ultra-stable mineral group (Hubert, 1962). Plotted as a group, their distribution is ubiquitous and shows no specific trends, but when plotted separately, two definite trends appear. This results because of differences in specific gravity, shape, and inherent size of the three mineral species; winds and waves transport each mineral type in a different way.

Zircon, as mentioned previously, shows the same distribution pattern as garnet and magnetite. Tourmaline (fig. 11), the lightest of the group (sp. gr. 3.1), is concentrated on the north beach and dunes east of Lake Wallace. Although it may be moved more easily than zircon, garnet, or magnetite, tourmaline is stable and would not be destroyed in transport. Its concentration, therefore, suggests that sediment has been moved into this region, i.e., toward the north and east. The distribution of rutile is irregular and does not comprise more than 2 percent of the transparent heavies.

Hornblende, hypersthene, and kyanite, somewhat lighter and less stable minerals, are grouped together because they show almost identical distributions (fig. 11). They are concentrated primarily on the northern portion of the island, being abundant where the more resistant and denser minerals are less common.

The remainder of the heavy mineral species, including staurolite, andalusite, epidote, and alterite, are irregularly distributed, but have a slight tendency to be concentrated on the northern portion of the island.

RELATION OF MINERALOGY TO GRAIN SIZE

In almost all samples, the percent of iron-stained quartz decreases with decreasing grain size (fig. 12). This progressive decrease in number of stained grains in smaller grain sizes reflects the relatively greater movement of smaller grains which, in turn, results in greater abrasion and, thus, the removal of stain on smaller grains. An exception is noted in samples from dunes on the south beach where all size fractions contain relatively large amounts of iron-stained quartz. This suggests that on the south side of the islands, sand is transported more directly onto the dunes with relatively less reworking.

Rock fragments tend to increase with increasing grain size in all environments, with a break in the size-frequency plot at about the 1.0 mm. size fraction (fig. 13). A break of this type does not occur in the similar quartz frequency-size plot. This phenomenon can be related to two factors: (1) relative resistance to abrasion and (2) critical wind velocities. Rock fragments of the types found on Sable Island are generally less resistant to abrasion than equivalent sized quartz grains. The average summer wind is about 13 mph. Bagnold (1941) estimates that wind must be stronger than 14.5 mph. to move grains greater than 1.0 mm. in diameter. Consequently, grains smaller than 1.0 mm. are subject to relatively greater movement, abrasion, and reduction in numbers than grains in the larger fractions.

INTERPRETATION

Textural analysis indicates that sediments on the northeast and southwest sides of the island reflect different physical conditions. The northeastern margin is subject to movement of sediment *en masse* with little or no selective sorting. This sector of the island is also an area of sediment accretion as illustrated by the formation of a second dune ridge north of the main dune chain. The southwestern margin, on the other hand, is subject to intensive selective sorting by wind and waves. Much sediment in this region also is being moved eastward by longshore currents.

Areas of excellent sorting on the island result from the removal of material by physical abrasion and selective transportation. Dense heavy minerals, including zircon, magnetite, and garnet, are concentrated as lag deposits by the selective sorting action of wind and water. On the other hand, heavy minerals of lower specific gravity (tourmaline, hornblende, kyanite) are winnowed out and deposited

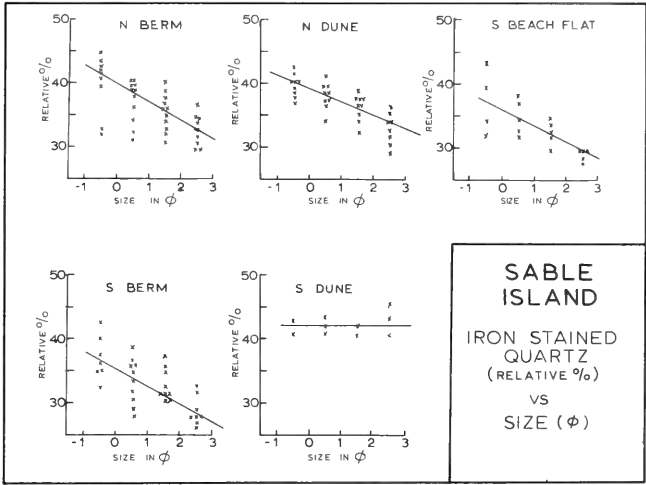


FIG. 12.—Relative percent of iron-stained quartz plotted against grain size for five different environments on Sable Island.

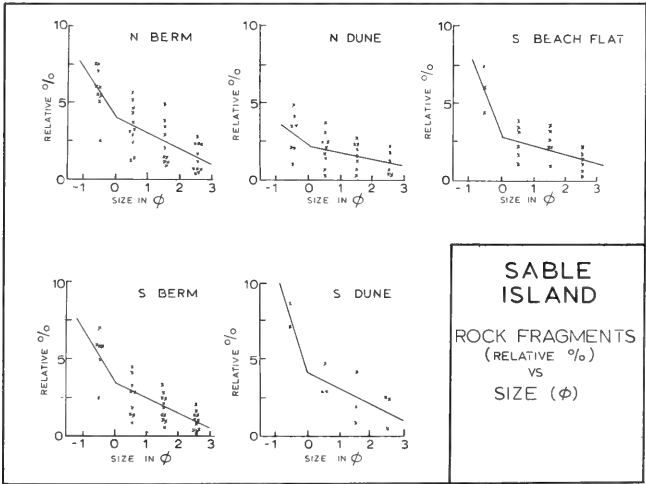


FIG. 13.—Relative percent of rock fragments plotted against grain size for five different environments on Sable Island.

downwind. This is demonstrated by the distribution of tourmaline (a light but stable species) that is always in association with hornblende, an unstable species; low specific gravity is their only common characteristic.

Mineralogical distribution patterns confirm the trends established by texture. The southwestern portion of the island is composed of clean sand with concentrations of heavies in the form of lag deposits. The northeastern margin is rich in iron-stained quartz and less dense heavies, suggesting that sediment has been transported into this area.

In summary, sediment on the island proper appears to be moving from southwest to northeast. A break at 1000 microns on the rock fragment-frequency distribution curve indicates that this size range is the threshold of grain saltation for wind velocities present on Sable Island. The decrease in rock fragments in the smaller size grains results because of the proportionally greater movement of smaller grains and because lithic grains are more easily abraided than quartz grains of equivalent size. The decrease of iron-stained quartz in the finer sand fraction is due also to the fact that smaller grains undergo relatively greater movement which results in the removal of their hematite coating.

DISTINGUISHING BETWEEN BEACH AND DUNE SANDS

GENERAL

One of the first workers to recognize the manner in which grain size is related to transporting medium was Udden (1914). In recent years, other methods involving visual examination of the grain size distribution curve (Doeglas, 1946) and of statistical techniques (Folk and Ward, 1957; Friedman, 1961) have been used to distinguish between various depositional environments.

Results of previous investigations have proven inconclusive. Mason and Folk (1958) and Friedman (1961) suggest a distinction between beach and dune sands on the basis of statistical parameters. Mason and Folk (1958) indicate that a skewness against kurtosis plot can be used to distinguish environments. Friedman (1961) found that a mean size against skewness plot can be used to distinguish environments. Shepard and Young (1961), however, found statistical parameters to be generally unreliable. Folk (1962, 1966) indicates that this unreliability is caused by the use of settling tubes instead of sieves. In each of the above investigations, however, skewness seems to be the statistical parameter that best distinguishes beach from dune

sands. Schlee *et al.* (1964), however, used Folk and Ward parameters calculated from both sieves and settling tubes and found that skewness provided inconclusive results.

TEXTURE

Sample data from each sector of the island was plotted separately as there is a large difference in parameter values between the north and south sides of the island. Two plots were constructed for each set of environments tested; (a) mean grain size versus sorting, and (b) skewness versus kurtosis.

Mean grain size versus sorting (fig. 14).—It is possible to distinguish berm, back beach and dune sands on the northern side of the island on a mean grain size versus sorting diagram. Berm sand is coarser (average mean size 0.420 mm.) and more poorly sorted than dune sand (average mean size 0.323 mm.), while sand from the back beach is intermediate. Values for beach sand are more dispersed than those for dune sand, indicating that wind is the more selective of transporting agents.

This type of diagram does not prove useful in differentiating sands on the southern portion of the island. Mean grain size for all environments varies only slightly (average 0.308 mm.) and there is considerable overlap of sorting values. This overlap suggests that there may be a constant transfer of sand back and forth between the beaches and dunes.

Samples were collected on opposite shores of Lake Wallace to ascertain whether the lake is affecting sediment distribution in the surrounding area. Sand south of the lake occupies a field similar to that of the south beach flats. Sand north of the lake, while having the same mean size, is more poorly sorted.

Skewness versus kurtosis (fig. 15).—A plot of the north beach berm, back beach and dunes sand indicates a broad overlap of values, due in part to the large lateral variation in skewness along the northern margin of the island. There is a slight tendency for dune sand to be more finely skewed than back beach sand.

A similar plot of sands on the south side of the island gives a slightly better separation. In going from berm to back beach to dunes, sands become more coarsely skewed. Beach flats and back beach sands on the island's south margin are nearly symmetrical to fine skewed. Sand south of Lake Wallace is fine skewed, whereas sand north of the lake is nearly symmetrical or slightly coarse skewed.

MINERALOGY

Shepard and Young (1961) indicate that texture alone is inconclusive and that dunes have mineralogical characteristics distinct from the beaches adjacent to them. Mineralogical parameters of beaches and dunes were compared following their technique but no diagnostic mineral differences were found between beaches or dunes.

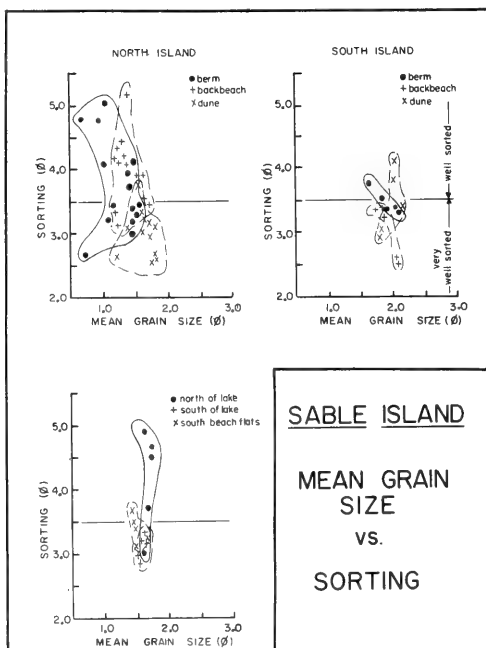


FIG. 14.—Plot of mean grain size versus sorting for beach, back beach and dune sands on both north and south sides of the island, as well as north and south of Lake Wallace.

INTERPRETATION

The interaction of wind and waves on sediment during the continuous back and forth transfer of sand grains between surf zone and dunes produces only subtle differences between Sable Island beach and dune sands. Distinguishing between beach and dune sands is made more difficult by the fact that sediments in this region, largely of relict Pleistocene origin, were moulded by a complex of aeolian, glacial, and fluvial processes in the recent past. These earlier processes, so important when Sable Island Bank was emergent during lower stands of sea level, left an imprint on sediments now

affected by a new set of depositional conditions (Stanley and Cok, 1965).

Certain selected mineralogical and textural parameters can be used for this purpose. A plot of mean grain size versus sorting proves to be the most valuable method of differentiation in high energy environments present on the northern margin of the island. In lower

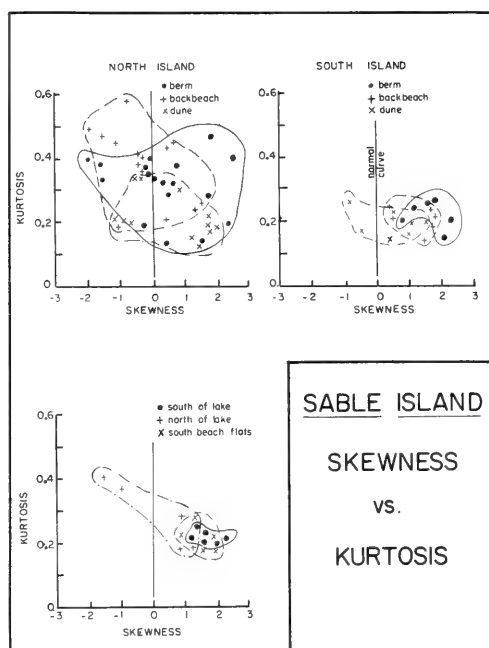


FIG. 15.—Plot of skewness versus kurtosis for beach, back beach and dune sands on both north and south sides of the island, as well as north and south of Lake Wallace.

energy environments, such as those present on the southern side of the island, a plot of skewness against kurtosis is more useful. Skewness becomes a sensitive indicator only when prolonged action of wind and water on an area produces similar sediment throughout the environments. Only then do the subtle differences between wind and water as agents of transport and desposition begin to emerge.

On the south side of the island, however, skewness values for beach and dune sands are exactly opposite to those found by Folk and Ward (1957) and Friedman (1961). Discrepancies of this type have been found by Friedman (1961) on Padre Island, Texas, and

Horn Island, Mississippi. The reversal of the pattern in both cases is caused by close association with a river from which fines are being added. A somewhat similar situation seems to be present on Sable Island: (a) winter winds from the north transport coarse and fine sand southward; (b) the finer material is first carried seaward and then returned shoreward by waves during the summer; (c) these fines never reach the dunes as the material is transported along the beach by longshore currents (evidence for this is presented in James and Stanley, *in press*); and (d) the dune material is resorted by gentle summer winds (from the southwest) that leave behind coarser grains which summer winds, unlike winter winds, are not capable of moving. This results in fine skewed beach material and coarse skewed dune material. The fines transported northward during the summer may account for the slightly fine skewed character of the northern dunes.

Shepard and Young (1961) indicate that dunes are enriched in heavy minerals and Giles and Pilky (1965) indicate that dunes are enriched in elongate mineral grains. These observations were not confirmed in the dune sands of Sable Island. The tendency is for the lateral distribution to mask mineralogical differences in adjacent beach and dune environments.

ENVIRONMENTAL FACTORS AFFECTING MORPHOLOGY AND SEDIMENT TRANSPORT

METEOROLOGY

Sable Island lies in a region affected by two major atmospheric pressure systems, the Iceland Low and the Bermuda-Azores High (Hachey, 1961). Winter winds average 20 mph. from the north and northwest while summer winds are lighter, averaging 13 mph. and blowing almost continuously out of the southwest. Precipitation is high during the winter and low during the summer. A small amount of winter precipitation falls as snow, and island residents report that during January, February, and early March the sand flats become frozen solidly enough for aircraft to land.

ORIGIN AND MAINTENANCE OF DUNES

Two large dune chains, oriented east to west parallel to the shore, form the backbone of the island. This linear dune chain resembles desert dunes described by Bagnold (1941) as longitudinal or sief dunes. Dunes of this type occur as continuous ridges that swell at

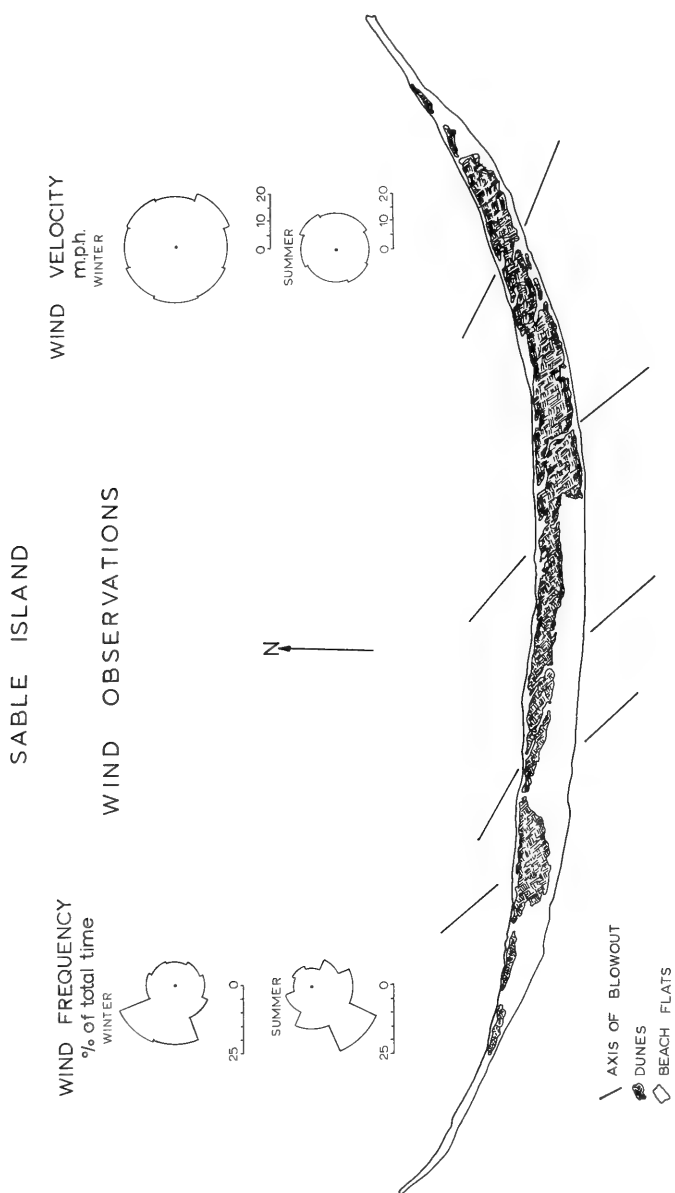


FIG. 16.—Seasonal variation of wind over Sable Island, compiled from long period climatological records of the Department of Transport, Meteorological Branch, for the period 1939 to 1965. Note that gentle summer winds blow dominantly from the southwest, while the more intense winter winds blow from the west and northwest, parallel to the alignment of blowouts.

regular intervals; such ridges form a chain of summits parallel to the *resultant* of two dominant wind directions. Cooper (1958), in his study of dunes along the Washington and Oregon coasts, refers to similar types as oblique dune ridges. Both workers agree that wind is the major controlling factor affecting these dune forms and that the complete wind regimen must be taken into account. Furthermore, Bagnold (1941) states "It is the relative angle between the directions of the mild winds and the storms that determines more than anything else the type of dune that is found in various parts of the world." Sable Island dunes are analogous to Bagnold's longitudinal dunes in that they are subject to winds from any quarter, but particularly from the northwest (winter winds) and the more gentle summer winds blowing from the southwest (fig. 16).

EFFECT OF SEASONAL WINDS

As the winds alternate with season, their effect on the overall morphology differs. During the summer months the combination of light wind and dry sand governs the composition and expression of the sand bodies. Gentle summer winds transport sand onto the dunes, increasing their height and shape. The eastward migration of sand on the island is indicated by mineralogical data presented previously. The northeast trend of dunes along the eastern end of the island suggests that the dominant direction of advance is controlled by summer winds from the southwest.

During the winter, winds blow from the west and northwest averaging 20 mph. with gusts to 70 mph., tending to destroy features formed during the summer. Along most of the north beach and some parts of the south beach, there are large breaches or blowouts in the dune face oriented in a northwest-southeast direction (fig. 16 and plate 2, fig. 1). None of the blowouts are oriented parallel to the summer wind direction.

The formation of blowouts seems to be the first step in the complete destruction of portions of the dune chain. Once cut off and isolated from the main dune chain, individual dunes are rapidly eroded. Isolated dunes are prevalent south of Lake Wallace where only 3 or 4 dune remnants can be seen on the broad flats (fig. 2). Cameron indicates that these were connected in a longer belt as recently as 1952.

Cameron's map (1965) shows a concentration of large "sand ripples" along the south beach which he attributes to incursions of the sea. Average wave length is about 15 to 20 feet and wave height is about 3 to 4 feet. These features could better be referred to as transverse ridges described by Smith (1954) and Cooper (1958).

Unlike longitudinal dunes, transverse ridges are a seasonal product that develop during the summer and are destroyed during the winter, a fact which explains their localized occurrence on the south beach.

ROLE OF VEGETATION

Marram grass is the most common plant on Sable Island. It occupies the dune crests and acts as a stabilizer in two ways: (a) it protects the surface and acts as a sand baffle trapping saltating grains from attack by winds, and (b) it binds the surface by a network of roots.

Grass cover results in breaks and irregularities in the topography along the length of the island. Wherever it is absent, for instance, large ellipsoid blowouts result. These blowouts differ from the long, linear, corridorlike blowouts on the north beach in that, being controlled by vegetation, they have no preferred orientation.

SEDIMENT TRANSPORT AND EVOLUTION OF SABLE ISLAND

RECENT CHANGES IN ISLAND SHAPE

The origin of Sable Island has been the subject of discussion by many who have visited it, scientist and traveler alike, since the early 1660s. MacDonald (1883, 1884, 1886), Patterson (1894, 1897), Macoun (1899), Fernald (1918), St. John (1921), Goldthwaite (1924), Erskine (1953) and others have discussed various aspects of this problem. Most theories emphasize the role of the Pleistocene ice sheets over parts of the Scotian Shelf and the fact that Sable Island Bank was subaerially exposed several times during the recent past. Glacial drift or fluvio-glacial outwash plain sediments (James and Stanley, *in press*) provided most of the sediment cover of Sable Island Bank and are the probable source of materials that gave rise to Sable Island. The postglacial rise in sea level has submerged glacial and fluvio-glacial deposits and subjected them to reworking by wave and current action.

A prevailing opinion of those who have studied Sable Island during the past 200 years is that it is eroding rapidly and is destined to vanish in the near future. The earliest description of the island appears in DeLaet's *Novis Orbis* of 1633 (*in* Patterson, 1894, p. 6):

It (Sable Island) is over 15 leagues (40 miles) in circuit, much longer than it is broad, the sea surrounding it being shallow and without harbours, and having a bad repute for shipwrecks. There is one small pond, but no springs of water on the island, many thickets of bushes, very few trees, the soil naked, but slightly covered with grass, and landing is difficult.

It is significant that this earliest description fits present observations so well, much better in fact than those of later workers.

Some of the records pertaining to the periodic destruction of the

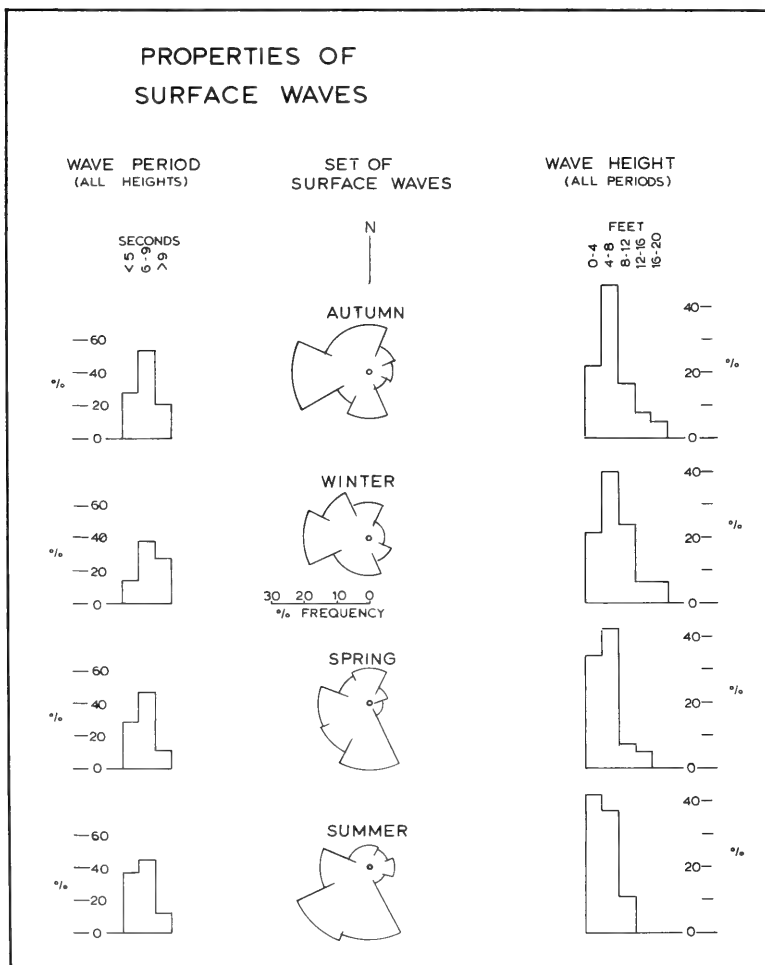


FIG. 17.—Characteristics of surface waves approaching Sable Island (compiled from the Climatological and Oceanographic Atlas for Mariners, vol. 1, North Atlantic Ocean, U.S. Office of Climatology and Division of Oceanography).

island are no doubt well founded: North Atlantic gales tend to leave a strong and lasting impression on visitors and occasional residents. As Willmore and Tolmie (1956) point out, however, accounts tend to be colored by the fact that recessions of the coastline have often

caused severe hardship and loss, and as a result attracted more attention than the accretion which has taken place slowly in other parts of the island.

Past assessments of the movement and wastage of the island have been based on observations taken over a relatively short length of time. In an attempt to remedy this confusion, Cameron (1965) has used charts published since 1766 and aerial photographs taken during the period 1952 to 1964 (fig. 18). In the past 200 years, the island appears to have lost 9 miles from the west end and gained 11 miles on the east end. Serious losses are attributed mainly to severe storms that have occurred spasmodically. The major conclusion, however, is that that island for quite some time has been 21 to 24 miles long and, if anything, has gained in length. The rapid seasonal change in shape and length of the emergent bars is probably the major cause of confusion in the literature.

NEARSHORE SEDIMENT MOVEMENT

The distribution of sediment, morphology and shape of the island is due to a balance between the destructive and constructive forces of wind and waves. Like the wind, the effect of waves on the island is markedly seasonal (fig. 17). Fall and winter are times of long period, high waves from the west and northwest, which decrease in intensity to a minimum during July and August. During spring the direction of approach changes almost 90° and waves set from the open ocean to the south and southwest.

The amount of sediment transport in the littoral zone is not due to the littoral current but to the waves themselves acting on the fore-beach (Saville, 1950). Winter storm waves account for only a small portion of the drift. Saville (1950) states,

These storm waves erode away large amounts of beach material, but this is not transported alongshore as littoral drift but is deposited almost wholly at depth seaward. It is, rather, the intermediate waves and summer waves of steepness of about 0.015 to 0.025 that do the major portion of transporting material along the shoreline.

The change in conditions from those prevalent on winter beaches to those prevalent on summer beaches is not a gradual one. The change occurs over a very small range of steepness values, with a critical H_o/L_o value (wave height/wave length) equal to approximately 0.03. Maximum transport along the shoreline occurs when this value lies between 0.020 and 0.025. Calculations for waves approaching Sable Island yield an average H_o/L_o value of 0.033 for winter waves and 0.021 for summer waves.

It appears that on Sable Island beaches maximum transport should take place along the forebeach zone of the south beach during the spring and summer months, while sand is eroded from the north beach during winter. This conclusion is supported by the steeper bottom gradient, indicative of erosion, seaward of the north beach, compared to the gentle gradient off the south beach (James and Stanley, in press).

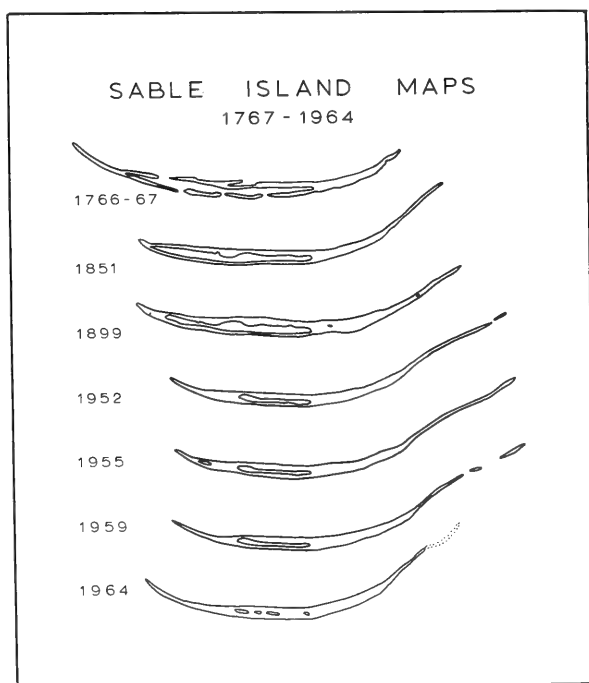


FIG. 18.—The evolution of Sable Island based on data summarized from surveys and charts dating from 1766 (after Cameron, 1965).

SEDIMENT MOVEMENT

Erosion of sediment from the north and addition of sediment to the south is contributing to the arcuate shape of Sable Island. Although dunes are breached during winter, sand added by summer winds from the southwest (see plate 2, fig. 2) prevents their complete destruction. There are two possible sources for south beach sand: (a) sand blown to the open ocean from blowouts during winter, (b) bottom sediment transported landward by long waves or surf beat from the open ocean to the south.

Our study suggests that Sable Island is not destined to be eroded and disappear as indicated in most earlier works. Storms cause considerable modification of the island's periphery and morphology, and changes in the length, shape, and orientation of the terminal bars are particularly noteworthy. Changes in the total length of the island, however, are only temporary, because cyclical movement of sand causes accretion as well as recession of the coastline. The net displacement of the island toward the east has taken place very slowly. Sable Island has narrowed somewhat during the past three centuries but has maintained its approximate length, arcuate shape, and geographic position on Sable Island Bank during this period.

SUMMARY

Sediment on Sable Island has originated from reworking of glacial drift and outwash materials deposited on the outer edge of the Nova Scotian continental shelf. During the last lower stand of sea level this sediment was subjected to prolonged aeolian conditions. A soil was formed approximately 6000 to 7000 years ago above older dunes when the climate was more suitable for abundant vegetation. Older sands below this paleosol are orange to red in color as a result of coatings of ochreous hematite added to quartz grains by intrastratal solution.

Abrasion and selective sorting have, since Holocene time, removed the iron stain and altered the mineralogical composition of sands above the paleosol making them mineralogically more mature. Lateral mineralogical and textural differences of these younger sands reflect different physical conditions on the north and south sectors of Sable Island. On the north, sand is moved *en masse* with little selective sorting, for the most part during storms of the autumn and winter months. On the southern portion of the island, sands are well sorted and of finer grade due to the gentle dry winds of summer which approach from the southwest. Distribution of iron-stained quartz, heavy minerals, and textural parameters indicates that at present net movement of sediment is to the northeast, the most important driving force being the summer winds from the southwest.

Beach and dune sands of the island have been differentiated on the basis of texture, not mineralogy. Where large-scale movement of sediment with little selective sorting takes place, beach and dune sands can be distinguished by plotting mean grain size against sorting. Dune sands in these areas are finer grained and better sorted than those on adjacent beaches. In areas where processes of selective sorting are particularly dominant, skewness and kurtosis can be used

to distinguish between beach and dune sands. Beach sands in such areas are fine skewed, a finding which differs from that of other workers.

Two parallel dune chains, oriented east to west along the length of the island, are maintained by winds that vary seasonally in direction and intensity. Strong autumn and winter winds from the northwest move large amounts of sand toward the southeast; weaker summer winds from the southwest sort the island sands and drive the dune chain in an eastward direction, the median between the two dominant wind directions. The coastline of the island, particularly the terminal bars, undergoes considerable seasonal modification and attrition; the total length of the island fluctuates continually because of this. It is the long-term net result of wind and wave action, however, that has caused a slow net displacement of the island toward the east and that has maintained the island's arcuate shape. Although winter winds blow sand seaward, this same sand eventually is returned to the island in a cyclical manner by wave action during the summer. In effect, therefore, erosion of the shoreline is matched by deposition of sand and accretion on other sectors of the island. The rapid rate of Sable Island's destruction, predicted in most previous studies, does not appear to us to be well founded.

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